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Balancing Privacy and Public Good in Wastewater-Based Epidemiological Surveillance

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ABSTRACT

Wastewater-based epidemiological surveillance has become a mainstream public health tool, tracking infectious disease, drug use, and other health indicators across entire communities without requiring individual cooperation or consent.

This review surveys the rapidly growing ethics literature that has followed this expansion, focusing on the central tension between the technique's public health value and the privacy, stigma, and equity costs it can impose on the specific, often small and already-marginalized populations whose wastewater is sampled most closely.

We examine how finer spatial resolution -- from citywide treatment plants down to single buildings -- shifts surveillance from a genuinely population-level signal toward something that functions as group-level, and sometimes near-individual, monitoring.

We then review proposed governance responses, including proportionality-based frameworks for deciding when finer-grained sampling and public data display are justified, technical privacy-preserving approaches such as encrypted data-sharing, and calls for more durable institutional and legal infrastructure than the emergency-response arrangements most current programs were built on.

We conclude that the ethical stakes of wastewater surveillance should be matched to its spatial resolution and the sensitivity of what it tracks, with community engagement and governance built into program design rather than added afterward.

Keywords: wastewater surveillance; public health ethics; privacy; group privacy; health policy

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INTRODUCTION

Wastewater-based epidemiological surveillance turns a municipal utility into a public health sensor. By

sampling what a community flushes, sheds, and excretes, health authorities can track the trajectory of an infectious disease, estimate the prevalence of illicit drug use, or monitor antimicrobial resistance genes across an entire sewershed without asking a single resident for permission [1]. The COVID-19 pandemic turned this once-niche environmental engineering technique into mainstream public health infrastructure almost overnight, and the practice has kept expanding since -- into monitoring for influenza, RSV, mpox, and a growing menu of other targets [2]. What makes wastewater surveillance ethically distinctive is not that it collects health-relevant data without consent -- plenty of public health surveillance does that -- but that it collects data about a population rather than about identifiable individuals, at least in principle, which has let many practitioners treat it as ethically weightless.

That framing is increasingly hard to sustain. A signal drawn from a single manhole can, at sufficiently fine spatial resolution, correspond to one building, one dormitory, or one household, at which point "population-level" surveillance starts to look a great deal like surveillance of identifiable people [3]. The ethical literature that has grown up around wastewater surveillance since 2020 is largely a literature about where exactly that line sits, and about what obligations attach to health authorities and researchers once they cross it. This article surveys that literature, focusing on the tension the title names directly: the genuine public health value of an early-warning system that requires no individual cooperation, set against the privacy, stigma, and equity costs that fall disproportionately on the specific, often small and already-marginalized communities whose wastewater gets sampled most closely.

FROM POPULATION SIGNAL TO GROUP-LEVEL DATA

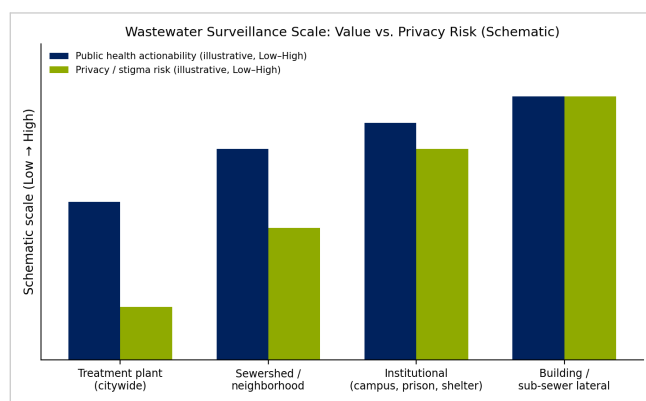
The core methodological virtue of wastewater surveillance -- that it aggregates biological material from many people before anyone examines it -- is also the source of most of its ethical complexity, because the degree of aggregation is a design choice, not a law of nature. A sample drawn at a wastewater treatment plant serving a city of a million people carries a very different privacy profile than a sample drawn from a single sewer lateral serving one apartment building or one skilled nursing facility. The National Academies' 2023 consensus report on wastewater-based disease surveillance treated this scalability as the central design tension for public health agencies: finer spatial resolution gives faster, more actionable signals, but at the cost of raising the population size small enough that surveillance starts to approximate individual monitoring [4]. Table 1 summarizes how the ethical stakes shift across four surveillance scales in current use, and Figure 1 places the same scales on a schematic axis of privacy risk against public health value, which is the trade-off practitioners are actually

navigating whether or not they name it that way.

Table 1. Ethical stakes of wastewater surveillance by spatial resolution, from citywide treatment-plant sampling down to single-building sub-sewer sampling.

Sampling scale	Typical population covered	Public health value	Privacy / stigma risk
Treatment plant (citywide)	Tens of thousands to millions	Broad early-warning trend for a whole city or county	Very low -- signal cannot be traced to any identifiable group
Sewershed / neighborhood	Hundreds to tens of thousands	Localizes outbreaks or drug trends to specific areas for targeted response	Moderate -- can stigmatize a named neighborhood or district
Institutional (campus, prison, shelter)	Dozens to a few thousand	Enables rapid, targeted intervention in a defined, high-risk setting	High -- population is small, bounded, and often already marginalized
Building / sub-sewer lateral	A handful of households or one facility	Fastest, most actionable signal for immediate local response	Very high -- approaches identifiability of specific households

Figure 1. Schematic comparison of public health value and privacy/stigma risk across wastewater surveillance scales (illustrative, not derived from a single empirical study).



Legal scholars analyzing wastewater surveillance's regulatory status have pointed out that most privacy law was written around identifiable individuals and simply does not have settled categories for group-level biological data drawn from shared infrastructure; a sewershed sample is neither obviously "personal information" under most data protection statutes nor obviously exempt from privacy obligations altogether [1]. A comprehensive scoping review of the ethics literature that accumulated around COVID-19 wastewater surveillance found that this ambiguity was not resolved by two years of rapid program expansion -- if anything, more programs launched before the legal and ethical questions were settled than after [5].

GROUP PRIVACY, STIGMA, AND THE LIMITS OF DE-IDENTIFICATION

Even granting that a wastewater sample rarely identifies a specific person the way a blood draw or a genetic sample does, the group it does identify -- the residents of a building, a campus, or a neighborhood -- can be harmed collectively in ways that individual-level privacy frameworks were never built to address. A 2024 analysis in *Water Research* argued explicitly for treating group privacy as a freestanding ethical category in wastewater surveillance design, distinct from and not reducible to the individual privacy interests the field usually reasons about, because a community can be stigmatized, over-policed, or economically disadvantaged by an inference about it even when no single resident is ever named [3]. Qualitative interviews with residents and public health practitioners have echoed this concern from the ground up: participants in a recent interview study repeatedly raised the worry that fine-grained wastewater data about drug use or disease prevalence, even when never linked to individuals, could still brand a specific dormitory, neighborhood, or workplace with a reputation its residents did not choose and cannot easily shed [6].

Sexually transmitted infections and HIV present a particularly sharp version of this problem, because the conditions wastewater surveillance is technically well suited to track are exactly the conditions carrying the deepest social stigma. Analyses of HIV wastewater monitoring have warned that even successfully anonymized aggregate data can produce real harm if it becomes public knowledge that a specific facility or neighborhood -- a shelter, a prison, an immigrant enclave -- has an elevated signal, since outsiders will draw conclusions about the people living there regardless of how carefully the underlying data was handled [7]. The same dynamic applies, with a different valence, to illicit drug monitoring: wastewater-based estimates of opioid, methamphetamine, and cocaine consumption have been used productively to evaluate the effects of scheduling changes and take-back programs [8,9], and longitudinal drug-monitoring programs abroad have tracked shifting local consumption patterns over years of repeated sampling in the same sewersheds [10], but a sewershed with an unusually high drug-use signal is also a sewershed that can attract more aggressive policing, more restrictive local ordinances, or diminished property values, none of which the residents actually using those services asked for or can meaningfully contest.

GOVERNANCE, TRANSPARENCY, AND COMMUNITY ENGAGEMENT

The dominant response in the recent literature has not been to argue that wastewater surveillance should stop, but that it needs governance structures proportionate to how finely it is deployed. The

Association of State and Territorial Health Officials' framework for addressing ethical considerations in wastewater surveillance recommends that health departments formally weigh public health benefit against privacy and equity harms before deploying finer-resolution sampling, rather than defaulting to whatever spatial granularity is technically achievable [11]. A parallel framework published in the *Journal of Public Health Management and Practice* similarly ties the acceptable level of surveillance detail to the severity and communicability of what is being tracked, arguing that fine-grained monitoring is easier to justify for an acute outbreak pathogen with clear protective actions available than for a chronic, stigmatized condition where residents can do little with the information besides feel exposed [12].

Displaying wastewater data publicly, once a program exists, raises a related but distinct set of questions from collecting it in the first place. A widely discussed ethics framework for wastewater dashboards proposed weighing five values together -- benefiting people while preventing harm, mitigating unfair disadvantage to already-marginalized communities, privacy, individual and collective autonomy, and good governance through transparency and accountability -- and concluded that outright privacy objections rarely justify withholding de-identified aggregate data entirely, but that stigma and equity concerns often justify coarsening its spatial or temporal resolution before publication [13]. Good governance, on this account, is less about a binary consent decision than about a series of proportionality judgments made at each stage: how finely to sample, how long to retain results, who gets to see disaggregated data internally, and how coarsely to present it externally.

Public attitudes research complicates any assumption that communities are simply hostile to being sampled. A nationwide survey of public perceptions in the United States found broad, if not universal, acceptance of wastewater monitoring for community health purposes, particularly for infectious disease outbreaks, alongside markedly less enthusiasm for extending the same infrastructure to track drug use or other socially sensitive behaviors [14]. That asymmetry suggests communities are drawing exactly the distinction the governance literature recommends -- between surveillance that serves a shared, urgent protective purpose and surveillance that mainly generates information that can be used against them -- even when the underlying laboratory methods are identical.

TECHNICAL APPROACHES TO PRESERVING PRIVACY

Some of the more recent literature has approached the privacy problem from the engineering side rather than the policy side, asking whether cryptographic and data-handling techniques can preserve the resolution public health agencies want while reducing the risk that a fine-grained signal gets misused or re-identified.

One 2024 study proposed an encrypted data-sharing architecture for wastewater-based epidemiology designed to let multiple institutions pool sample data for analysis without any single party holding an unencrypted, geographically resolved dataset [15]. Good laboratory and ethical practice guidance published alongside this work has increasingly recommended that sample retention periods, chain-of-custody protocols, and data-sharing agreements be treated as core parts of the surveillance program's design from the outset, rather than compliance add-ons addressed after a program is already collecting data [16]. There has also been early discussion of formal biobanking of wastewater samples for longitudinal research, which would extend the surveillance relationship indefinitely and raises, in a smaller and more novel form, some of the same retention and future-use questions that have long occupied genomic biobank ethics [17].

None of these technical measures resolve the underlying governance question on their own. Encryption and access controls can reduce the number of people capable of misusing fine-grained data, but they do not answer whether a given level of spatial resolution was justified to collect in the first place, or who should decide that on a specific community's behalf. Communicating results responsibly once they exist is its own discipline: recent guidance on communicating wastewater-based surveillance data emphasizes that even accurate, well-intentioned public messaging can produce panic or complacency depending on how uncertainty and limitations are conveyed, independent of any privacy question [18].

INSTITUTIONAL DESIGN AND PUBLIC HEALTH INFRASTRUCTURE

Underneath the specific ethical debates sits an institutional one: wastewater surveillance in most jurisdictions developed through ad hoc partnerships between academic laboratories, private testing companies, and local health departments, assembled quickly during a public health emergency and never fully re-architected once the emergency passed [19]. Programs built this way often lack the standing ethics review, community advisory input, or formal data governance structures that a purpose-built surveillance system would have included from the start. Proposals for a more durable national wastewater surveillance system have argued that sustaining the public health value of the tool over the long run requires exactly the institutional investment that the emergency-response origins of most current programs skipped -- clear statutory authority, dedicated funding independent of outbreak cycles, and formal mechanisms for the communities being sampled to weigh in on how finely and how publicly their sewershed's data will be used [20].

CONCLUSION

Wastewater-based epidemiological surveillance is neither the privacy-free public health tool its early advocates sometimes described nor the surveillance overreach its harshest critics allege. It is a genuinely valuable early-warning capability whose ethical cost is real but uneven, concentrated at the finer spatial resolutions and more socially sensitive targets where a "population-level" signal starts to function as information about an identifiable, often already-disadvantaged group. The literature surveyed here converges on a proportionality-based answer rather than a categorical one: match the spatial resolution and public disclosure of a surveillance program to the severity of what it tracks and the availability of protective actions residents can actually take, build governance and community engagement into program design rather than bolting it on afterward, and treat group-level privacy and stigma as first-order ethical concerns rather than as a residual category left over once individual identifiability has been ruled out. Getting this balance right will only matter more as the range of conditions wastewater surveillance can detect keeps expanding faster than the governance frameworks meant to keep pace with it.

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Conflict of Interest

The authors declare no conflicts of interest relevant to this work.

Author Contributions

Miguel Steiner conceived the review, coordinated the literature synthesis, and drafted the initial manuscript. Sanne Wisniewski developed the sections on group privacy, stigma, and technical privacy-preserving approaches, and critically revised the manuscript. Katarzyna Mendes contributed the sections on governance, community engagement, and institutional design, and gave final approval of the submitted version. All authors read and approved the final manuscript.

Ethics Statement

As a literature review synthesizing previously published, publicly available research and policy analysis, this article did not involve new data collection from human participants and did not require institutional ethics committee approval.

Data Availability

No new data were generated or analyzed for this review. All sources discussed are cited in the

reference list and are publicly available through their respective publishers.

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